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IT-2-P-1600 Phase Contrast Transfer Function for Differential Phase Contrast in High Resolution Local Electric Field Measurements

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Differential Phase Contrast (DPC) is a contrast mechanism that can be utilized in the Scanning Transmission Electron Microscope (STEM). Since the advent of DPC, the technique has been used to image magnetic fields within a specimen [1]. To this end, a ring detector is divided into four quadrants and the direct electron beam is placed within the ring, only overlapping a small part of the detector. In a classical interpretation, the direct beam is slightly tilted by the magnetic fields in the specimen, so that subtraction of different detector segement signals yields DPC. Recently, this DPC geometry was also employed to investigate local electric fields with high resolution [2,3].

To determine whether this interpretation of DPC is still valid in high resolution, the wave nature of the electrons has to be taken into account. This can be done by calculating the Phase Contrast Transfer Function (PCTF) [4] to examine the contrast mechanism. For DPC, the PCTF should be proportional to the spatial frequency $k=2\pi/\lambda$ whereas a PCTF constant as a function of the spatial frequency k would indicate conventional phase contrast.

Assuming an ideal lens, which is a good approximation for an aberration corrected STEM, the PCTF for a weak phase object can be calculated using elementary geometry. A cut through the two dimensional PCTF, evaluated for the parameters of a local electric field measurement, is shown in fig.1. It is striking that the area in which the PCTF is proportional to k is rather small (up to ca. 0.2 1/Å as seen in fig. 2), indicating that, for high spatial frequencies, DPC would not occur. While this is unproblematic at low resolutions (where the configuration described above leads to an improved signal to noise ratio [5]), it suggests that under these conditions the classical model is not valid for high spatial frequencies and the detector setup is therefore not suited for high resolution DPC applications.

The calculated PCTF shows that, for the given parameters, DPC is limited to spatial frequencies of about 0.2 1/Å. We are currently looking for possibilities to increase the resolution by optimizing the detector geometry.

[1] J. N. Chapman et al., Ultramicroscopy 3 (1978) 203
[2] M. Lohr et al., Ultramicroscopy 117 (2012) 7
[3] N. Shibata et al., Nature Physics 8 (2012) 611
[4] H. Rose, Ultramicroscopy 2 (1977) 251
[5] J. N. Chapman et al., IEEE trans. on magn. 26 (1990) 1506

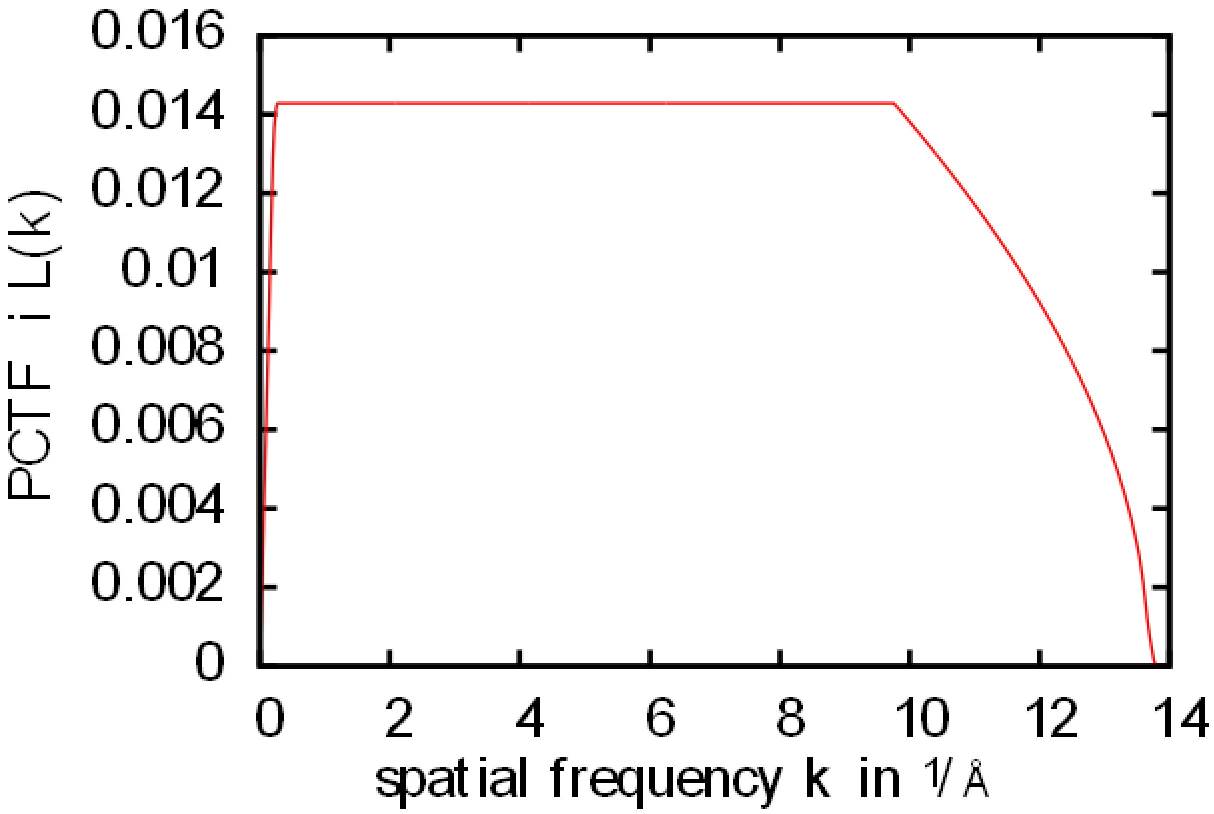

Fig. 1: PCTF L(k) for an ideal microscope with an acceleration voltage of 300 kV, an aperture angle of 21.6 mrad, an inner detector angle of 21.0 mrad and an outer detector angle of 40.7 mrad, corresponding to the configuration in high resolution local electric fields measurements.

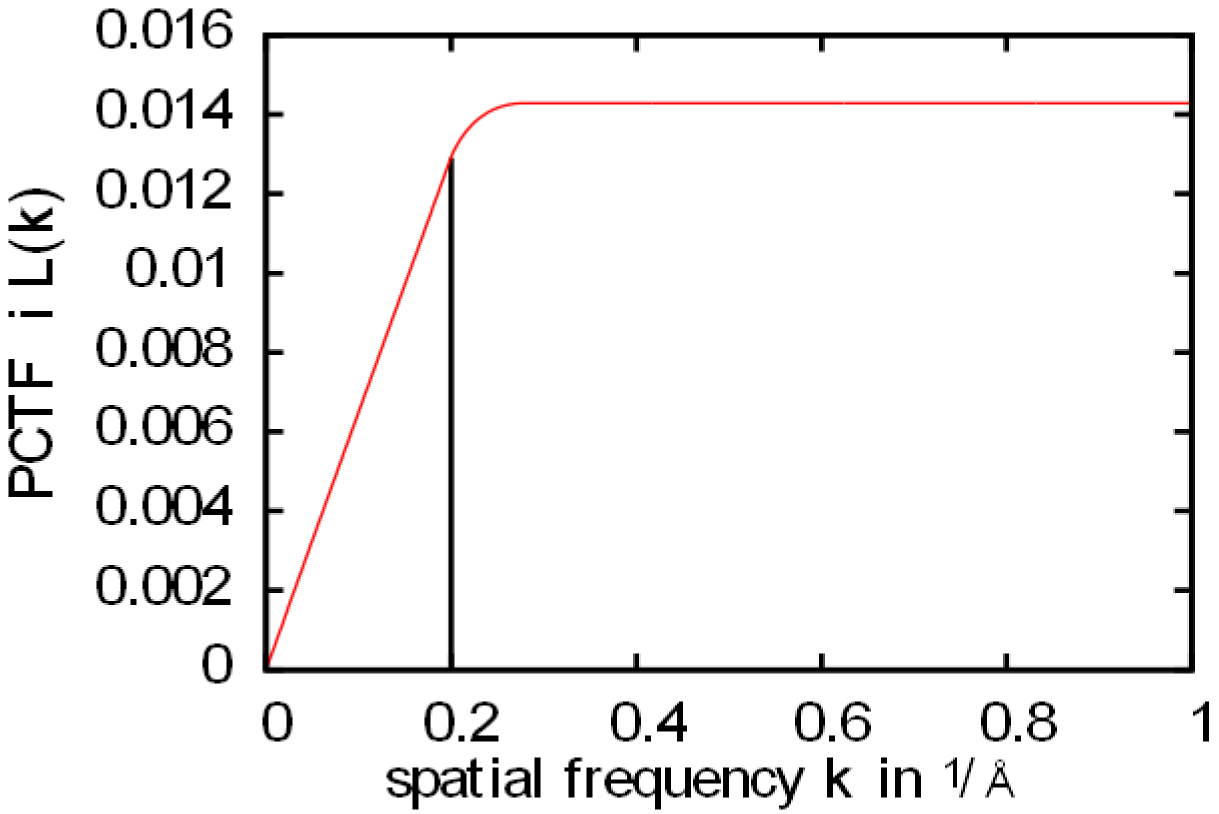

Fig. 2: Low spatial frequency region of the PCTF in fig.1, showing that DPC only occurs for spatial frequencies k smaller than ca. 0.2 1/Å.